Geometric and Radiometric Calibration Topics Relevant to Skybox Imaging

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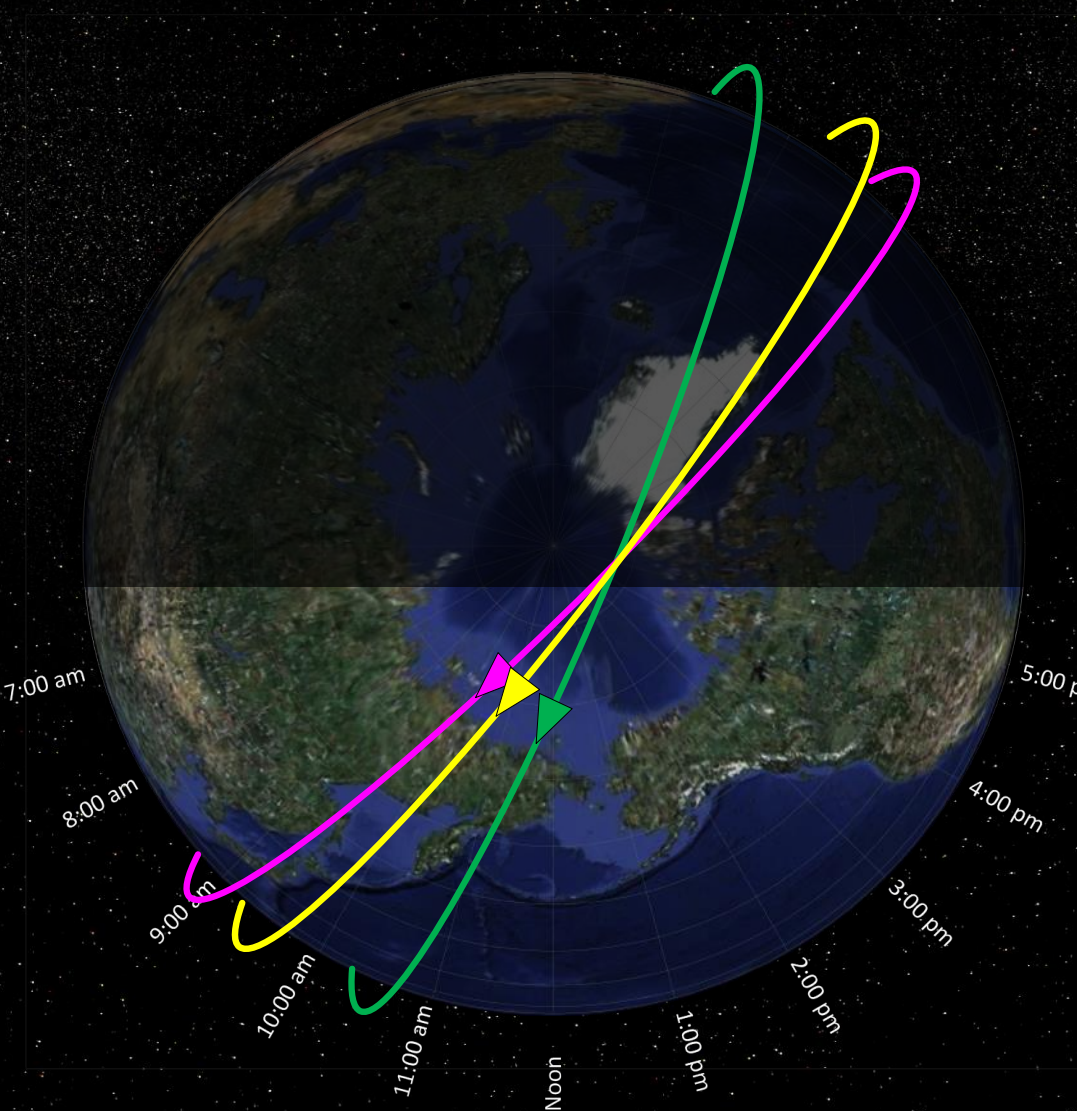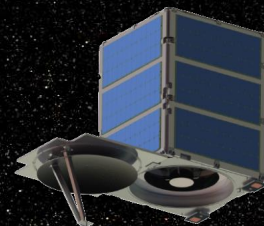
7 May 2015

outline

- satellite overview

- geometric calibration
  - RPCs that comes with L1B products
  - bundle adjusting Geo products to remove shear

- image quality - MTF

- radiometric calibration – bad pixels

- conclusions

SATELLITE OVERVIEW
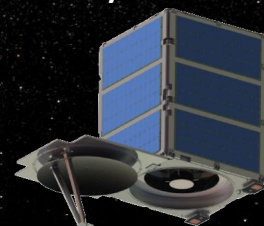
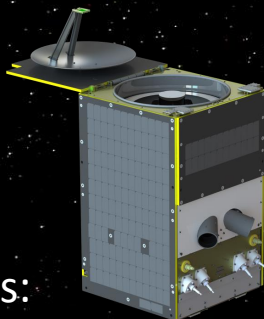# These are the Skybox satellites

SkySat-1

- no propulsion
- launched on Dnepr, 21 Nov 2013
- ~600 km, 10:30 am sun sync orbit

SkySat-2

- no propulsion
- launched on Soyuz, 8 Jul 2014
- ~635 km, 9:00 am sun sync orbit

SkySat-3

- has propulsion
- current launch plans:
    ~500 km, 9:30 am sun sync orbit

SkySat-3 has some improvements

SkySat-3 is our second generation satellite

~15 cm taller

~30 kg heavier

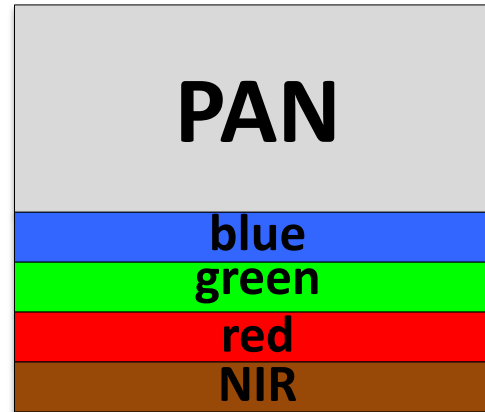| SkySat-1, 2	SkySat-3
reaction wheels	better reaction wheels (5x slew rate)
no propulsion	propulsion

Skybox intends to launch more SkySat-3 class satellites!

SkySat-1, 2, and 3 use this focal plane

focal plane shown as projected to the ground!

detector 2

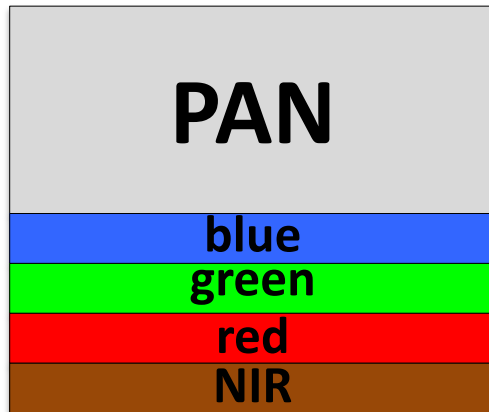**PAN**

blue
green
red
NIR

"pushframe" **sensor**

entire arrays captured at each frame time

detector 3

PAN

blue
green
red
NIR

scan direction

detector 1

PAN

blue
green
red
NIR

SkySats collect imagery like this

SkySat-1 collect 20150202_714a56c43992 plotted in UTM zone 38P

northing

2

3

1

Aden

frame 1

easting

RGB image courtesy of Landsat-8, bands 4, 3, 2

Aden, Yemen

north of the sub-solar point,
images are collected in this orientation,
with detector 2 **lagging,**
door down

animation frame rate set to 40 Hz, same as the real collect,
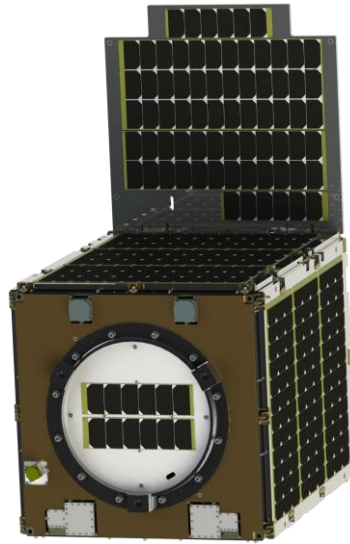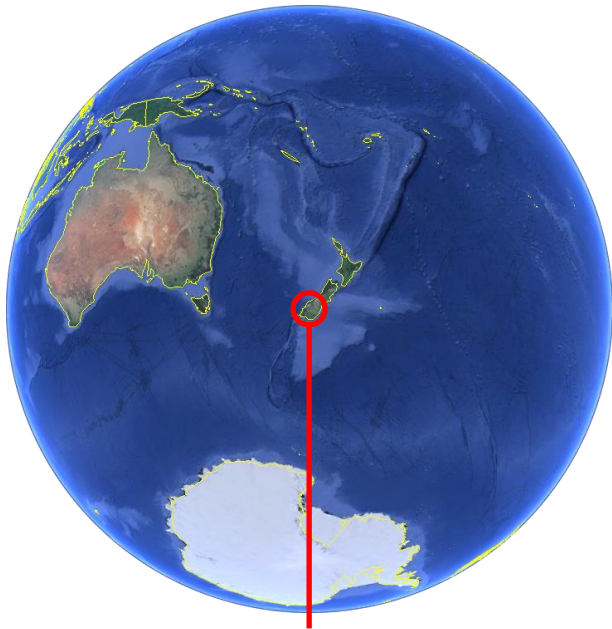*⇒ real time animation!*

SkySats collect imagery like this
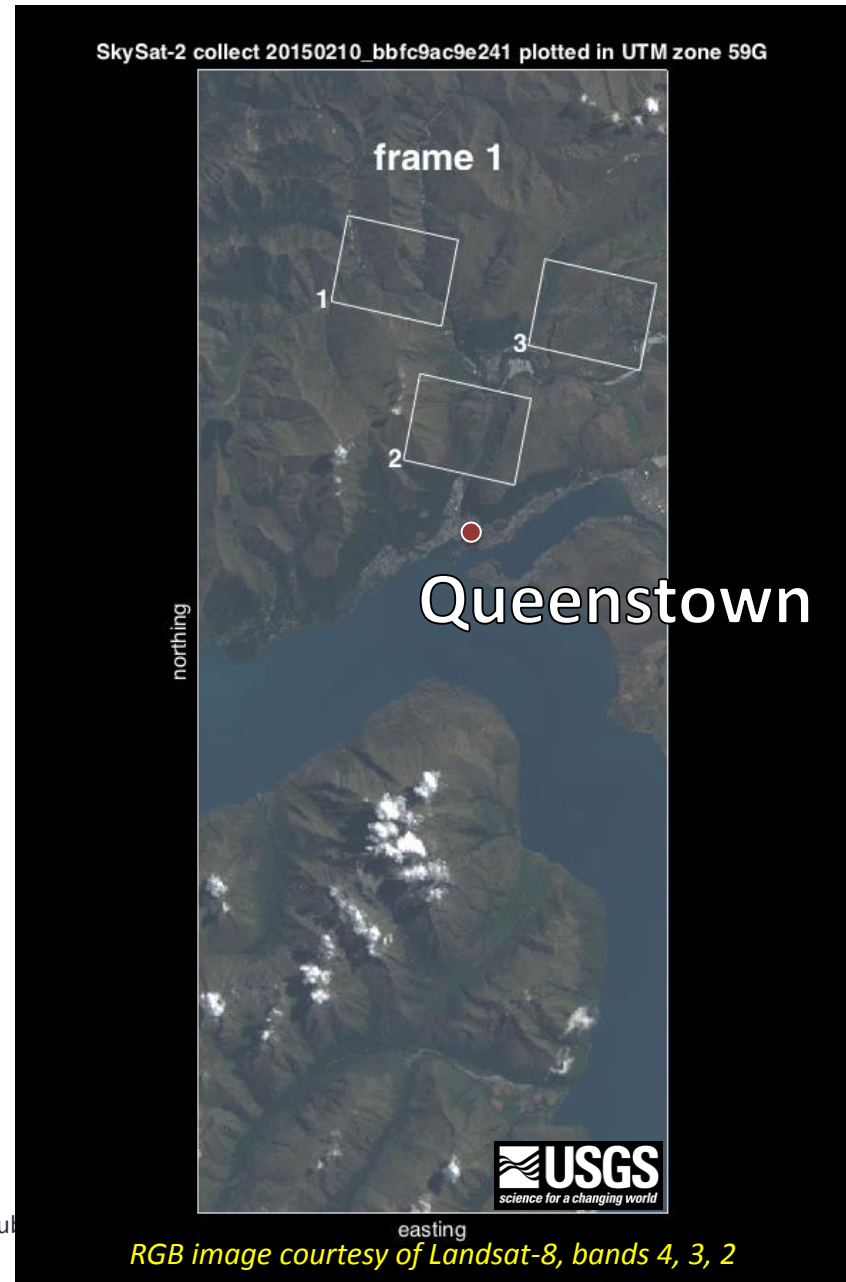

Queenstown, New Zealand

south of the sub-solar point,
images are collected in this orientation,
with detector 2 **leading,**
door up

animation frame rate set to 40 Hz, same as the real collect,
⇒ real time animation!

SkySat-2 collect 20150210_bbfc9ac9e241 plotted in UTM zone 59G

frame 1

1

3

2

Queenstown

northing

easting

RGB image courtesy of Landsat-8, bands 4, 3, 2

GEOMETRIC CALIBRATION

recall this focal plane collects pixels

detector 2

PAN

blue
green
red
NIR

detector 3

PAN

blue
green
red
NIR

scan direction

detector 1

PAN

blue
green
red
NIR
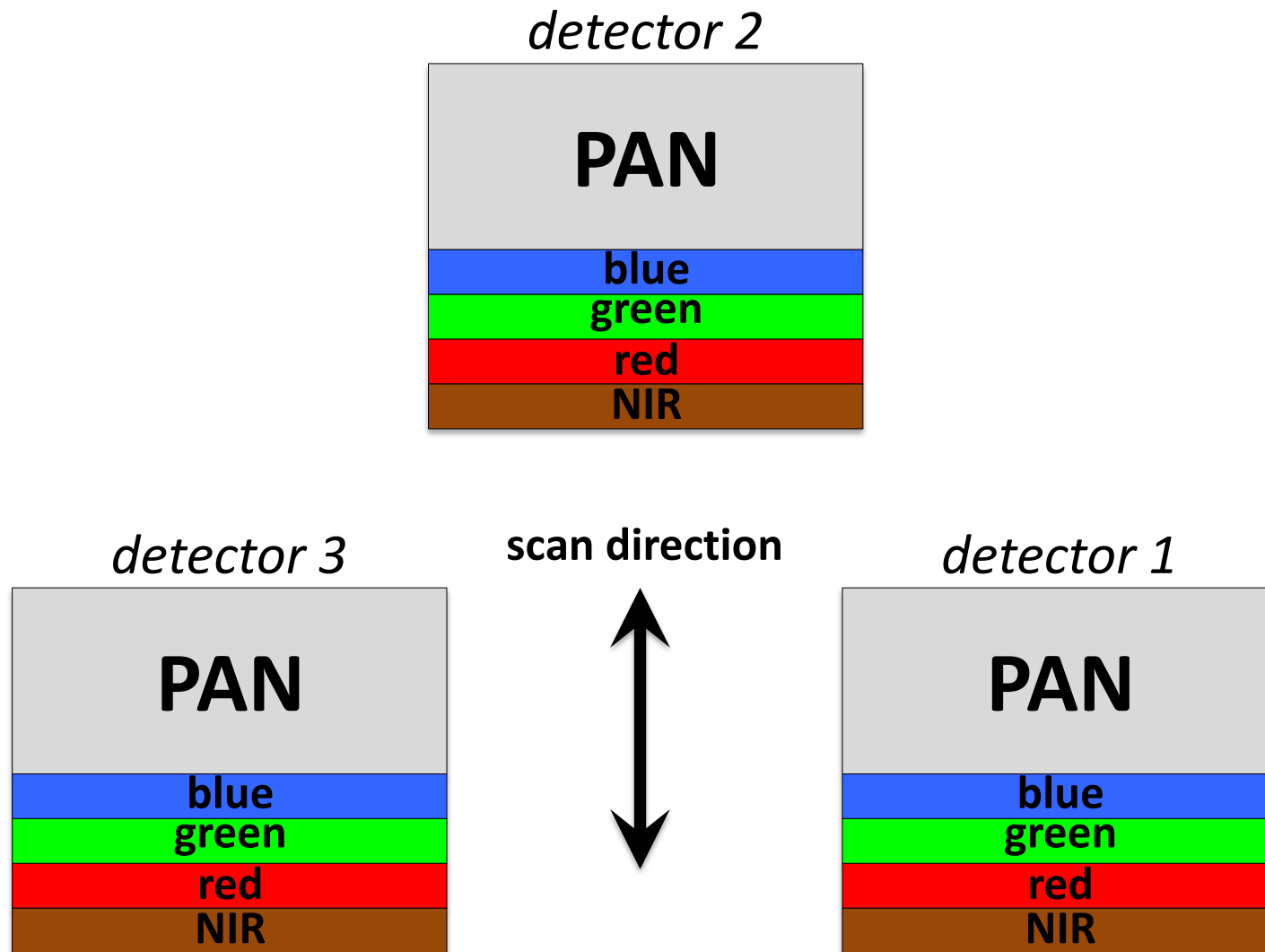
L1Bs are made upon the PAN half

detector 2

PAN

each PAN tile is superresolved†, using 15-50 raw frames;

(exact number depends on ground scan rate of the boresight,
3.5 km/s ≈ when a point on the ground is seen in 15 frames)
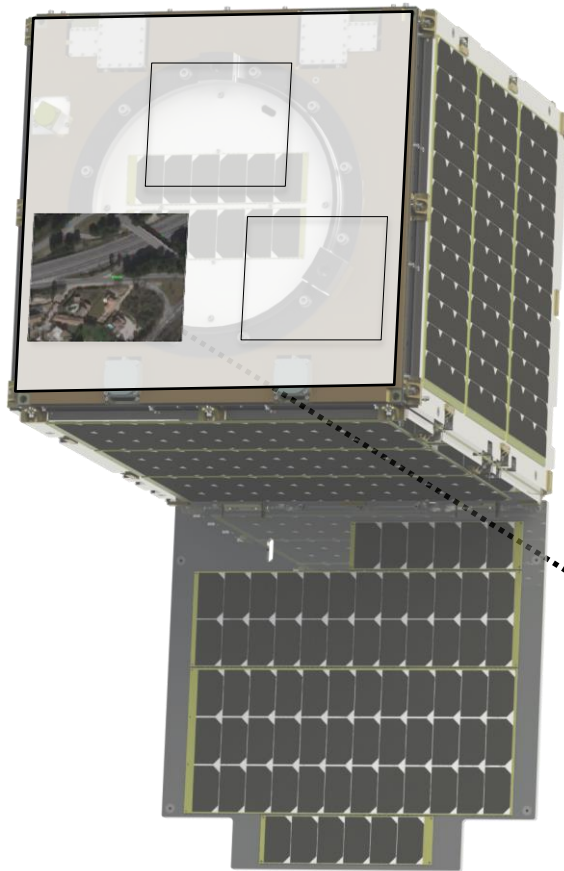
detector 3   **scan direction**   *detector 1*

PAN   **PAN**

each MS band is registered to PAN, creating MS and pansharp tiles

L1B RPCs match the rigorous model

project a point to the ground with the rigorous model...

$$l = \frac{Num_L(U,V,W)}{Den_L(U,V,W)},$$

$$Num_L(U,V,W) = a_1 + a_2 \cdot V + a_3 \cdot U + a_4 \cdot W + a_5 \cdot V \cdot U + a_6 \cdot V \cdot W + a_7 \cdot U \cdot W + a_8 \cdot V^2 + a_9 \cdot U^2$$
$$+ a_{10} \cdot W^2 + a_{11} U \cdot V \cdot W + a_{12} \cdot V^3 + a_{13} \cdot V \cdot U^2 + a_{14} \cdot V \cdot W^2 + a_{15} \cdot V^2 \cdot U + a_{16} \cdot U^3 + a_{17} \cdot U \cdot W^2$$
$$+ a_{18} \cdot V^2 \cdot W + a_{19} \cdot U^2 \cdot W + a_{20} \cdot W^3$$

$$Den_L(U,V,W) = b_1 + b_2 \cdot V + b_3 \cdot U + b_4 \cdot W + b_5 \cdot V \cdot U + b_6 \cdot V \cdot W + b_7 \cdot U \cdot W + b_8 \cdot V^2 + b_9 \cdot U^2$$
$$+ b_{10} \cdot W^2 + b_{11} U \cdot V \cdot W + b_{12} \cdot V^3 + b_{13} \cdot V \cdot U^2 + b_{14} \cdot V \cdot W^2 + b_{15} \cdot V^2 \cdot U + b_{16} \cdot U^3 + b_{17} \cdot U \cdot W^2$$
$$+ b_{18} \cdot V^2 \cdot W + b_{19} \cdot U^2 \cdot W + b_{20} \cdot W^3$$

AIX006

...then unproject the ground location back into the image using the RPCs...

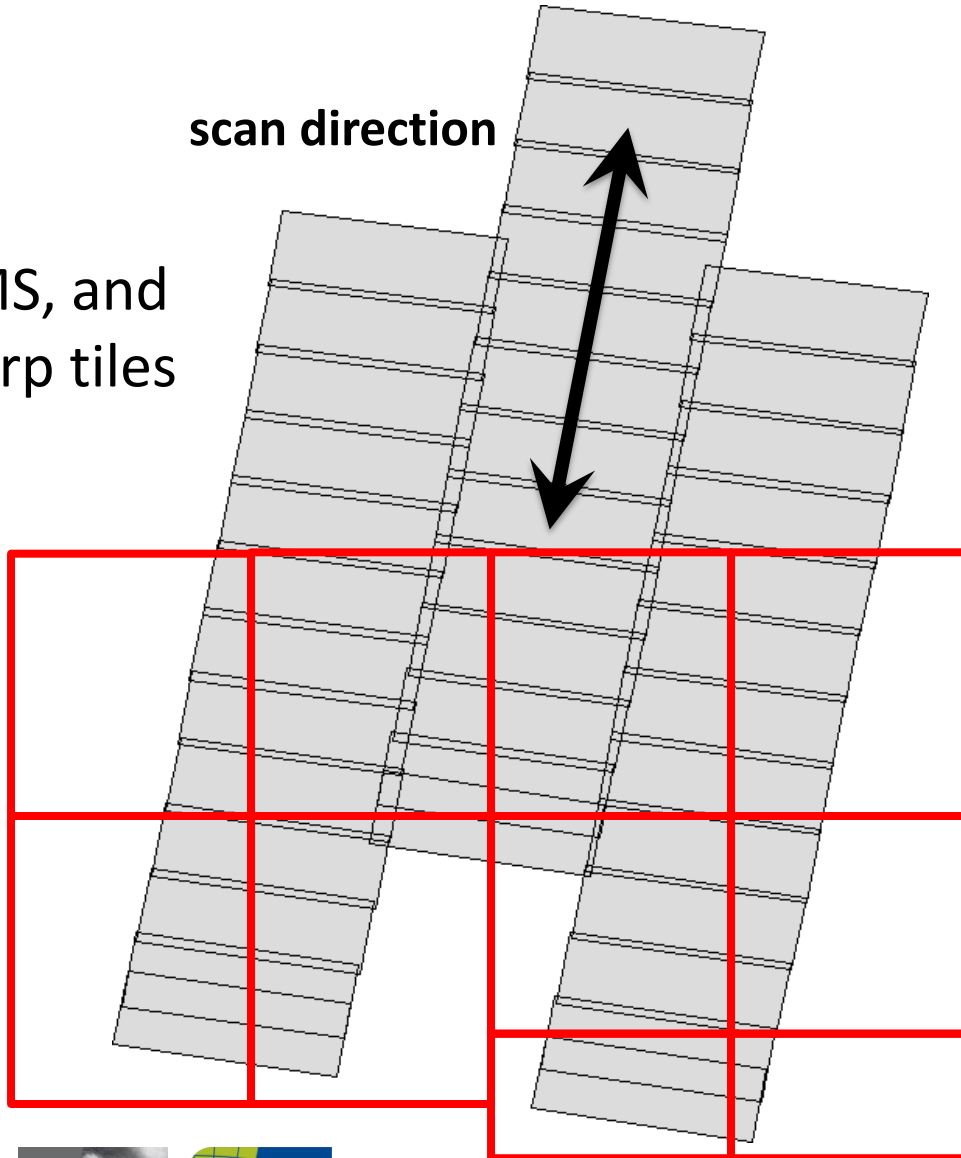...and note the pixel coordinates are nearly the same:
Δline = **0.084951 rows**
Δsample = **0.035114 columns**

Skybox also makes Geo products

scan direction
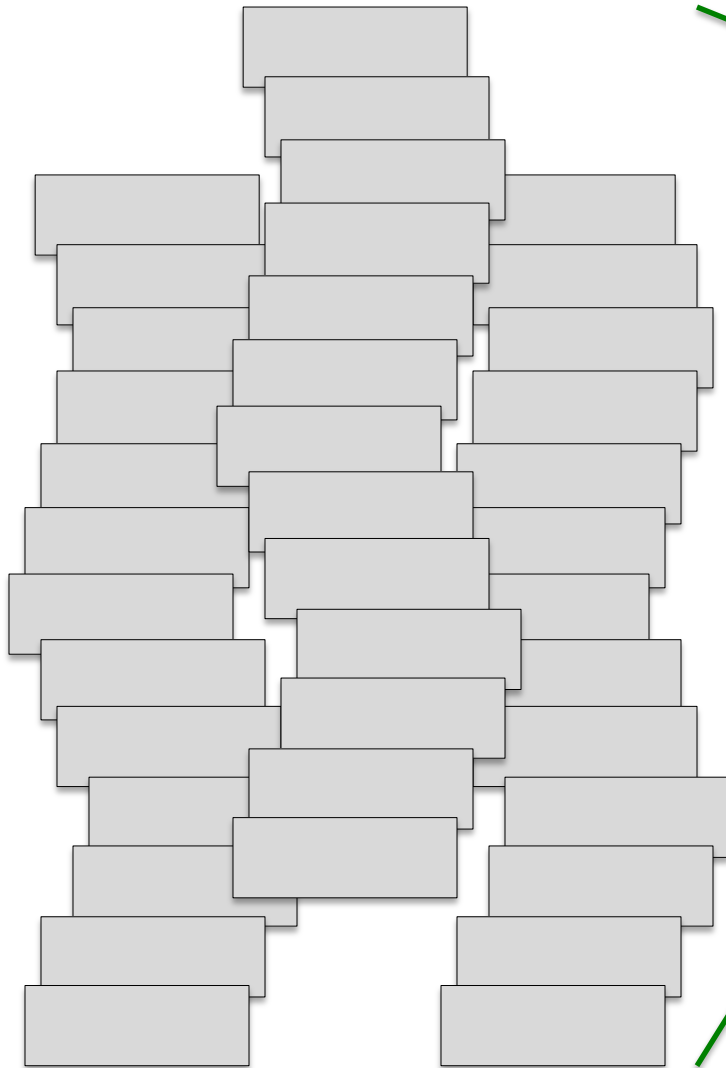
PAN, MS, and pansharp tiles

Geo product

L1B pixels projected to a constant height above geoid, then re-tiled

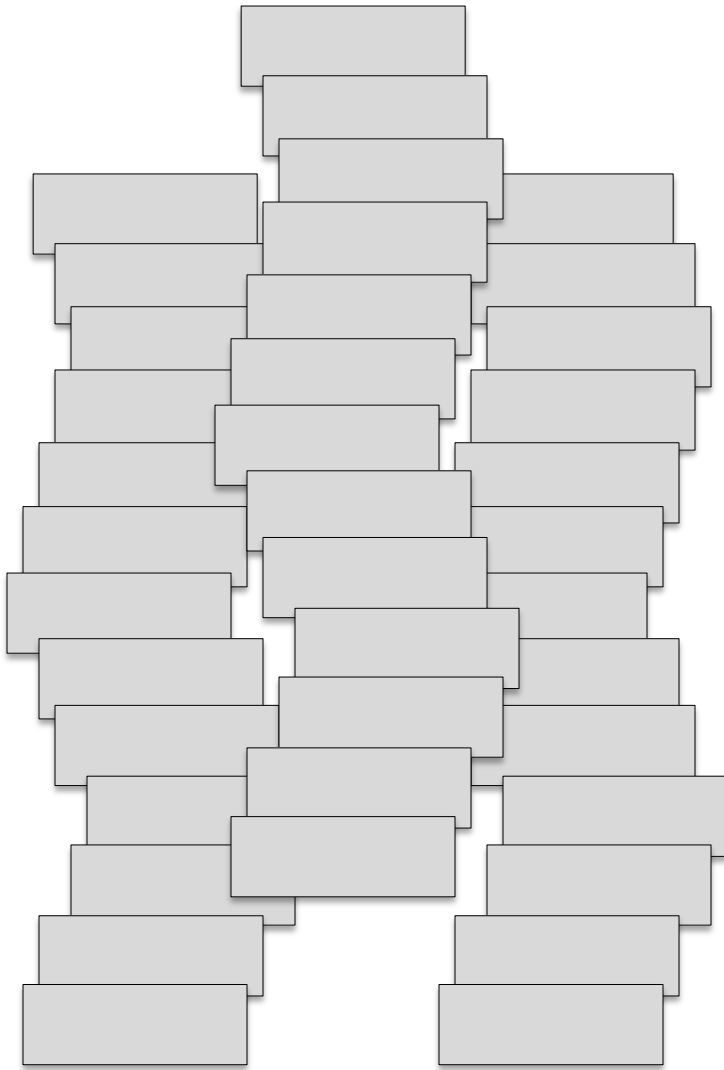mosaicked! RPCs for each tile!
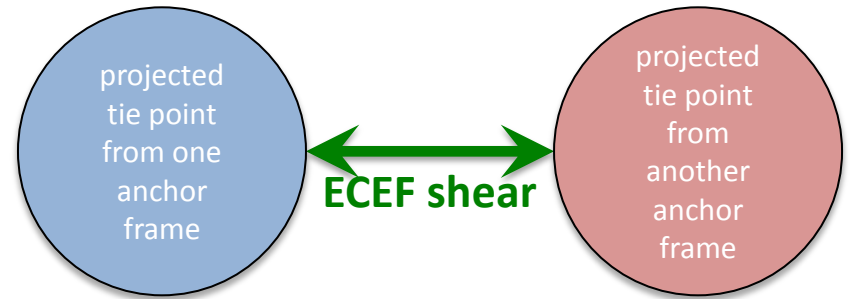
Geos are made from projected L1Bs

(attitude noise wildly exaggerated for emphasis)

- projected L1Bs don't fall in a perfectly straight line
- star tracker noise affects the georeferencing of individual L1B frames

bundle adjustment fixes the Geo

projected tie point from one anchor frame ← **ECEF shear** → projected tie point from another anchor frame

- tie points in overlap regions provide refinement

- a least squares fitter is tied into the projection model

⇒ quaternion (orientation, pose) for each anchor frame is *rewritten*

⇒ minimizes shear between anchor frames

! note how all three detectors are moved together, rigidly… sub-pixel interior orientation allows this! (see JACIE 2014 slides)

(least squares fit also wildly exaggerated for emphasis)
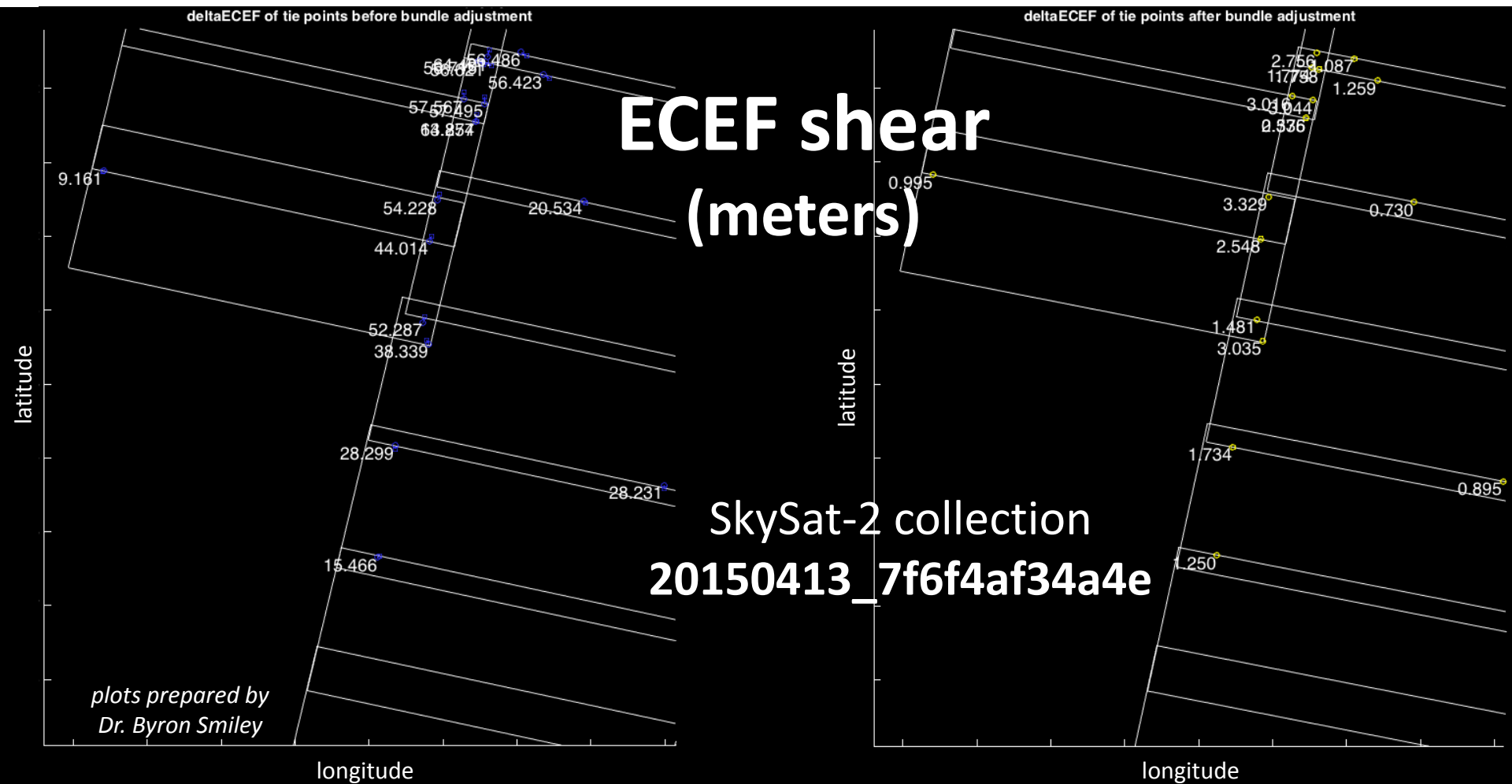
any collect can reveal the ECEF shear
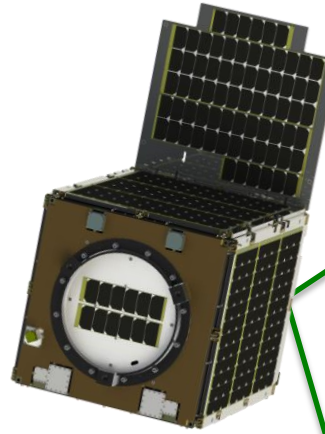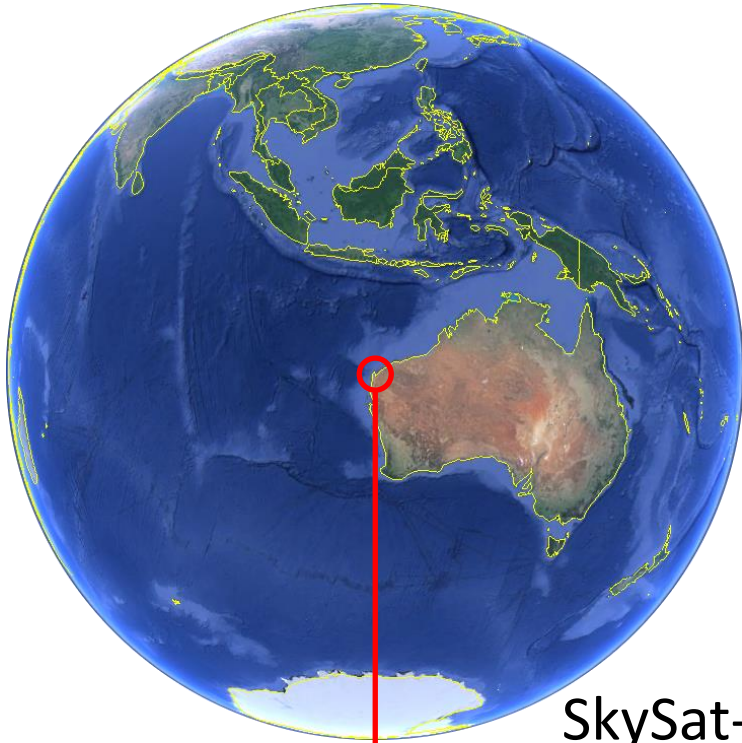
SkySat-2 collection
20150413_7f6f4af34a4e

North West Cape, Australia

featured in the next slide

the ECEF shear is removed

deltaECEF of tie points before bundle adjustment

deltaECEF of tie points after bundle adjustment

**ECEF shear
(meters)**

**SkySat-2 collection
20150413_7f6f4af34a4e**

*plots prepared by
Dr. Byron Smiley*

post-adjustment ECEF shear very low, but not zero

Why not zero? Because most tie points didn't lie at that constant elevation above the geoid!
(although tie points with less than a meter of shear afterward probably did…)

MTF

IMAGE QUALITY

Skybox imaged Stennis, cloud-free!

multiple times by SkySat-1, two examples will be shown today:

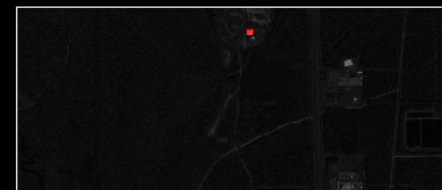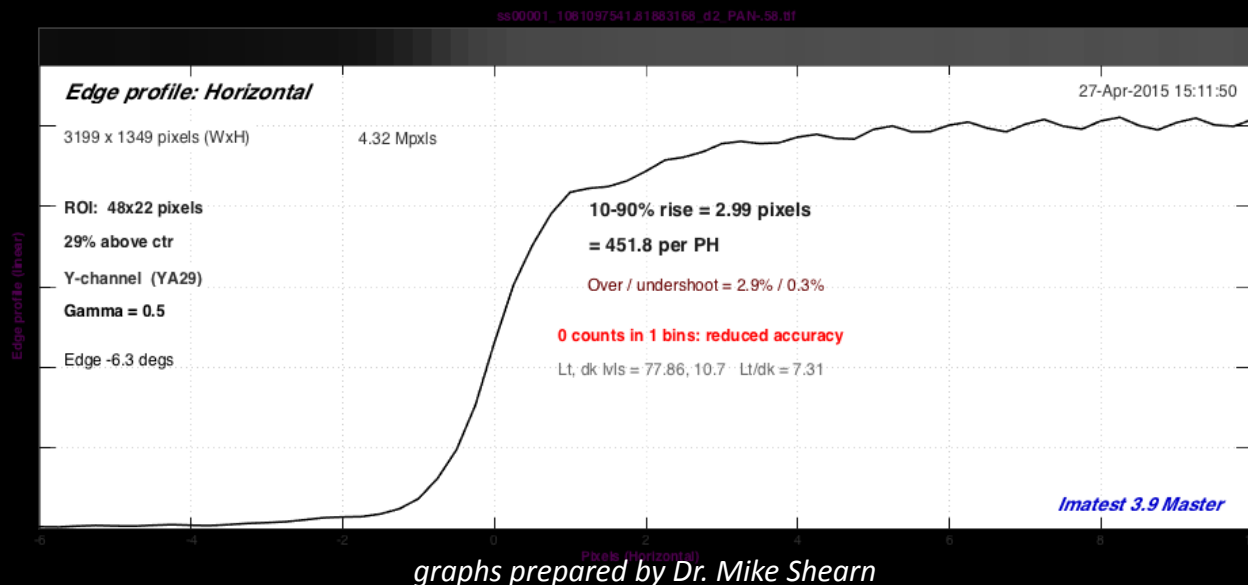20140409_163120_004000 - wideraw
20150126_27a255383ca5 - conventional

20150126_27a255383ca5 L1B pansharp tile

50 meter x 50 meter
2x2 checkerboard

John C. Stennis Space Center (30.385571° N, 89.628521° W)

Skybox Imaging - approved for public release

L1B processing preserves contrast

the L1B PAN tile was used for this MTF measurement

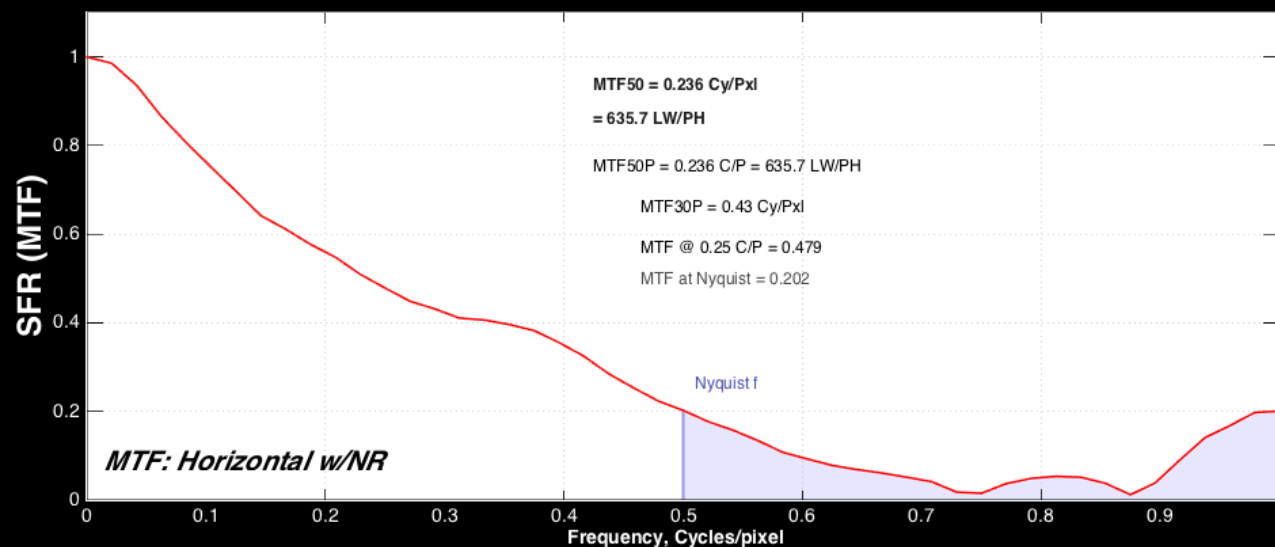*graphs prepared by Dr. Mike Shearn*

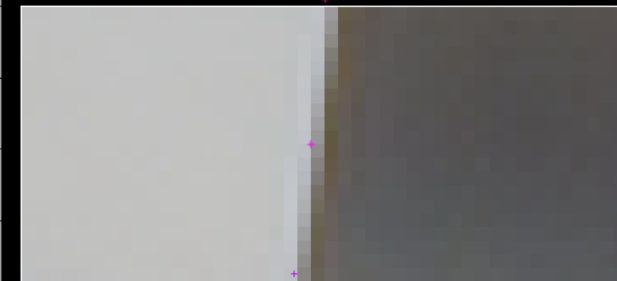# SkySat-1 collect
20140409_163120_004000

this was a "wideraw" collect, meaning the imagery was downlinked as tiff, NOT j2k

⇒ MTF not affected by j2k compression! Just the optics and superresolution† algorithm

pansharp MTF was also checked

the L1B pansharp tile was used for this MTF measurement

graphs prepared by Dr. Mike Shearn

we're working to reduce the blue sharpening...
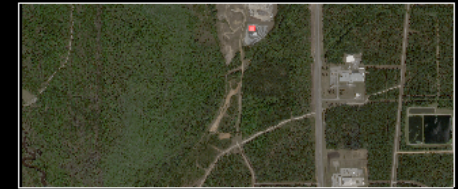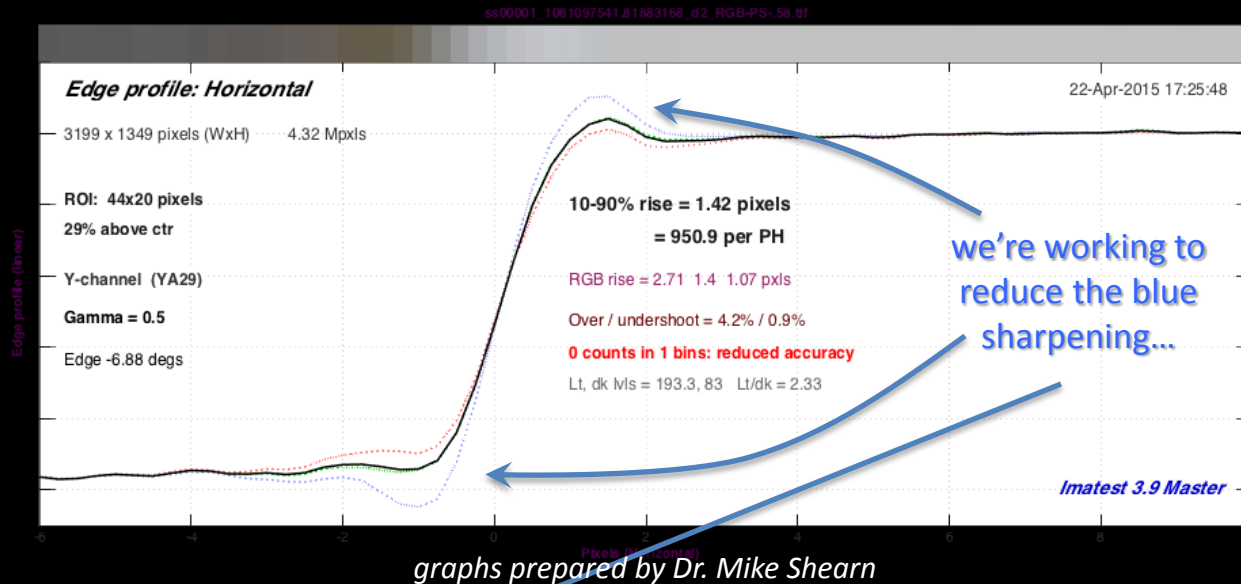
SkySat-1 collect
20150126_27a255383ca5

this was a conventional collect, meaning the imagery was downlinked as j2k

⇒ *MTF influenced by:*
- *optics*
- *j2k compression*
- *superresolution[†] algorithm*
- *pansharpening algorithm*
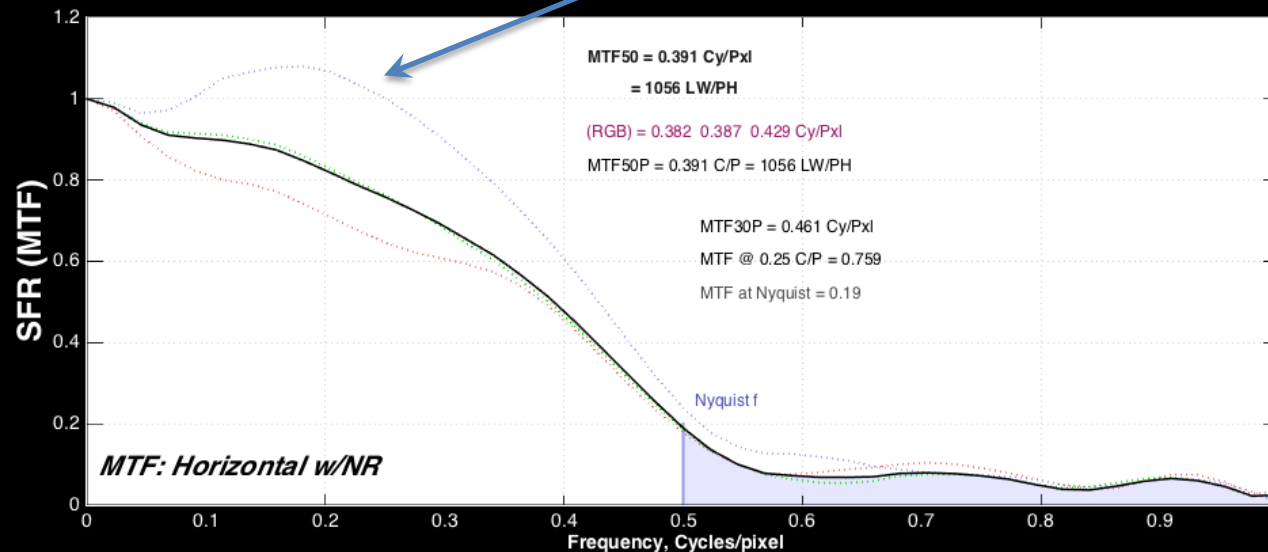
bad pixels

RADIOMETRIC CALIBRATION

bad pixels spoil images and videos

radiometric artifacts are called many things: bad, hot, dead pixels

representative detector array

hot pixel

bad pixel

Skybox preferred terminology

dead pixel

and they constantly appear due to radiation! (and rarely go away by themselves)

Skybox corrects bad pixels

bad pixels are typically discovered at three times:

1. **post-launch calibration** – "we expected trouble"
2. **add single** – specific product failures – "our QC/QA team found trouble"
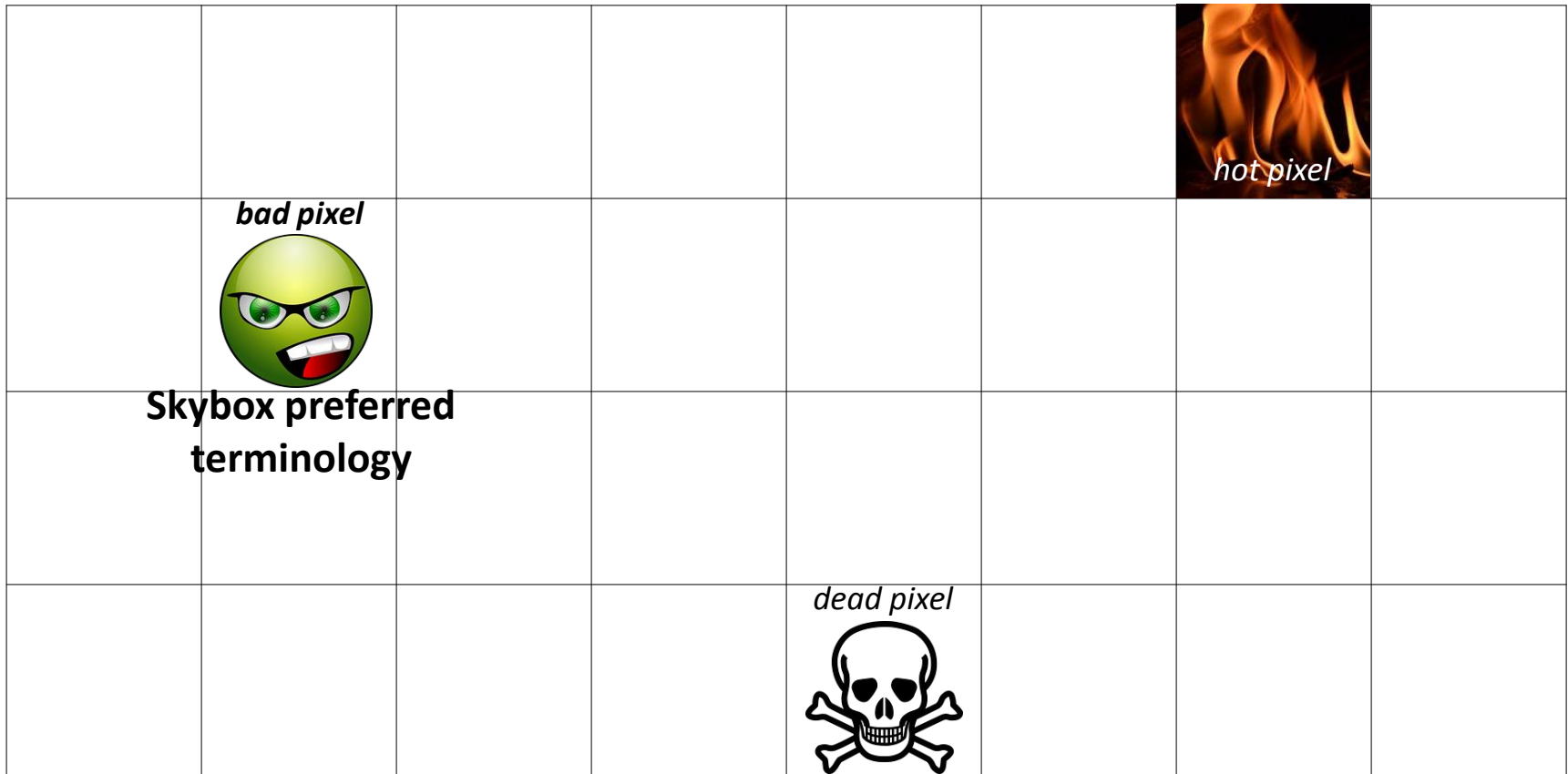3. **reassess all** – periodic investigation to find them - "Alexandra went looking for trouble"

timeline of bad pixel detection
rounded to the nearest month

SkySat-1

Launch SkySat-1

Post-launch cal
Post-launch cal

Reassess all

Add single

Add single

Nov 2013 Dec Jan 2014 Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan 2015 Feb Mar Apr May

Add single

Reassess all

SkySat-2

Post-launch cal

Launch SkySat-2

bad pixels appear on *monthly* timescales, mostly from radiation

timeline prepared by Dr. Alexandra Chau

bad pixels hover in Raw Videos

in an unstabilized Raw Video product, bad pixels dwell in a single spot

SkySat-2 Raw Video 20140916_48f1d6ddc8ed (Nishinoshima Island)

Nishinoshima Island

30 Hz Raw Video

the bad pixel lived here on detector 2

columns

Raw Videos look better after correction

applying the bad pixel mask during processing removes the artifact

SkySat-2 Raw Video 20140916_48f1d6ddc8ed (Nishinoshima Island)

Nishinoshima Island

30 Hz Raw Video

what bad pixel?

columns

bad pixels traverse a pansharp, MS

a bad pixel leaves a line of artifacts* in a pansharp,
it's where the bad pixel lived in the raw MS frames

*similar effect to a bad pixel on a TDI sensor

before correction

number of artifacts
proportional to the
ground scan rate

SkySat-2 collect 20140808_79aa74dc14c9
~11 km outside Norberg, Sweden

pansharps look better after correction

all the artifacts are removed by applying the bad pixel mask to the MS raw frames, prior to pansharpening
(note the PAN tiles never showed this, due to superresolution†)

after correction

number of artifacts proportional to the ground scan rate

SkySat-2 collect 20140808_79aa74dc14c9
~11 km outside Norberg, Sweden

CONCLUSIONS

conclusions

- SkySat-3 will be different than SkySat-1, 2 in these ways:
  - smaller pixels
  - increased agility to collect more area
  - propulsion for orbit stationing
- Geo products are corrected in post-processing – ECEF shear minimized at that height above geoid
- analysis of a wideraw L1B collect shows that our contrast/MTF is preserved by:
  - good construction; instrument is not misaligned, out-of-focus, etc
  - the superresolution[†] algorithm
- Skybox has mature processes for detecting and correcting bad pixels, in area collects and videos

references

† superresolution algorithm detailed in the following publication:

Kiran Murthy, Michael Shearn, Byron D. Smiley, et al., "SkySat-1: very high-resolution imagery from a small satellite", *Proceedings of SPIE Vol. 9241*, 92411E (2014)